TMET-R-00-101

Final Report

Delivery of a Pulse Detonation Rocket Engine and Pulse Detonation Thrust Stands to NASA Marshall Space Flight Center

Submitted to:

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This report is Task 4.0 for the Purchase Order Number H32310D titled "Delivery of a Pulse Detonation Rocket Engine and Pulse Detonation Thrust Stands to NASA Marshall Space Flight Center". It is the final deliverable of this purchase order.

The scope of this project was to deliver a bench scale pulse detonation engine and thrust stands for use in pulse detonation research. Included was support in the operation of the engine and of testing that occurred with the thrust stands.

Chronologically the principle activities that occurred under this purchase order were:

1: A pendulum thrust stand, horizontal/vertical linear thrust stand, and a ballistic calibration device were designed, built, tested, and used at NASA Marshall and at White Sands, New Mexico. These stands were built in support of the light craft laser induced detonation project.

2: A detonation initiator tube was designed, built, and tested for use as the ignition source for pulse detonation engines. This tube was designed as a high energy input device to start detonation waves in primary tubes.

3: A bench scale pulse detonation engine was designed, built, mated with the initiator tube, and tested. Testing has continued up to the time of this report with modifications being made as necessary to improve operation.

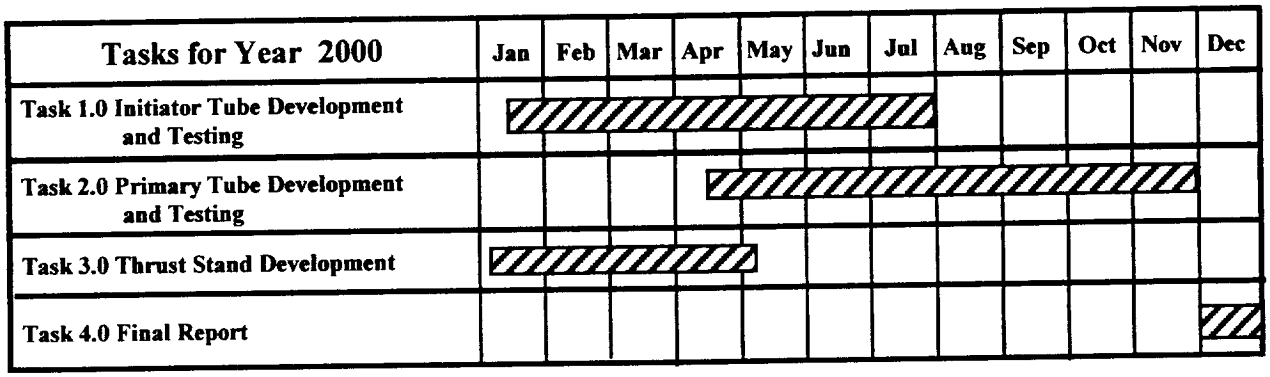
4: Instrumentation as necessary was added to test items to determine operational parameters and collect performance data.

5: TMET personnel aided in the configuration of the test area as necessary to accommodate the pulse detonation device and thrust stands. This including running gas lines, control signal cables, setting up test equipment, etc.

6: Plans were made to expand the pulse engine research next year.

Task Schedule

Below is shown a schedule of activities carried out in year 2000 with a summary of tasks that took place under this purchase order following. Work has been accomplished on all tasks as of this report and items as outlined in the statement of work including drawings and hardware that have been turned over to NASA personnel.



Task Time Frame

Task 1.0 Initiator Tube

The object of this task was the design and construction of an initiator tube for use in a pulse detonation rocket engine. Designed was a compact device that used a spark ignition system to start a detonation wave in a small tube before exiting into the larger primary tube.

Two initiator tubes were built for this task, the first as a tool to verify the design and the second for use in the primary tube. Both were designed for use with hydrogen and oxygen at near stoichometric mixtures. The design consists of an annular injector with hydrogen flowing in the center and oxygen in the annulus. Fuel and oxidizer are feed to the annular injector thru stainless steel tubing from solenoid valves, one for the fuel flow and two for the oxidizer flow due to the larger requirements for oxygen when firing with hydrogen. The tube itself is about ½ inch in diameter and has a sparkplug as its ignition source. The sparkplug is powered by a capacitive type automotive ignition system which has been modified for control with TTL signals. The ignition system and valves are powered by a 12-volt DC power supply. The gases are supplied from K-bottles by standard regulators.

The control system developed for the initiator was written in LabView and is run on a PXI based system. The control program allows the signal timing including delay and duty cycle to be easily changed. The computer outputs TTL level signals. To protect the computer and to boost the signal power an optical isolation and signal amplification box was made. The TTL level signals from the computer enter the box and are converted to optical signals which travel down short optical cables. The signals are then received and turned back into voltage signals. The two sides of the system are totally isolated with separate positive and ground buses. The TTL signals control solid-state relays and transistor switches at the test stand.

The verification tube was built with four ports down its length with the necessary connections for fast response pressure transducers to be mounted. A picture of the tube after testing is shown in Figure 1. The hydrogen valve is in the center left while the oxygen valves are above and below. Red LEDs used as diagnostic tools are seen near the valves and were used to give an indication of the valve operation. The two pressure transducers can be seen at the end of the barrel on the right. The purpose of these transducers was to determine if the initiator tube was producing a detonation wave and what frequency. The speed of a detonation wave in hydrogen/oxygen mixtures is about 2400 m/s. It can be seen in Figure 2 that a detonation is being produced by the initiator tube. The initiator tube has been run at frequencies up to about 36 Hz. It does appear to operate more reliably in open air than once mounted in a tube due to the gas dynamics however it will function in the tube. Testing of this tube also showed that during proper operation, when detonating, no water-cooling was necessary.

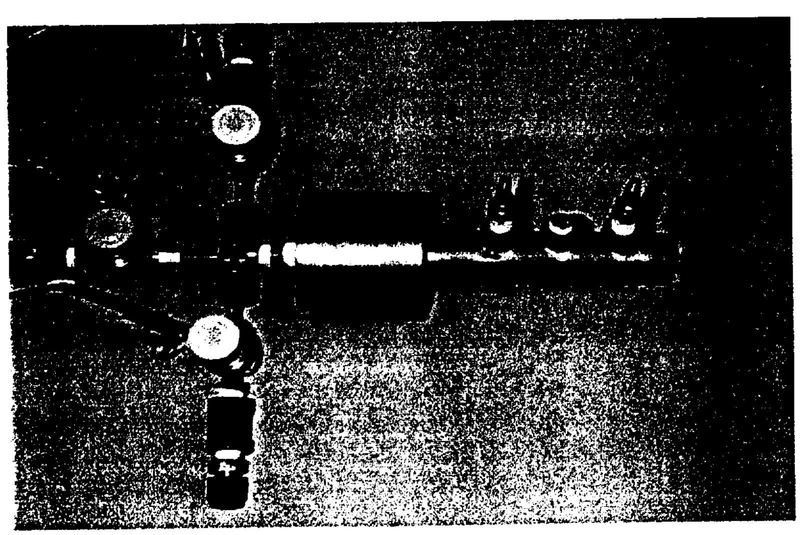


Figure 1. Validation Tube

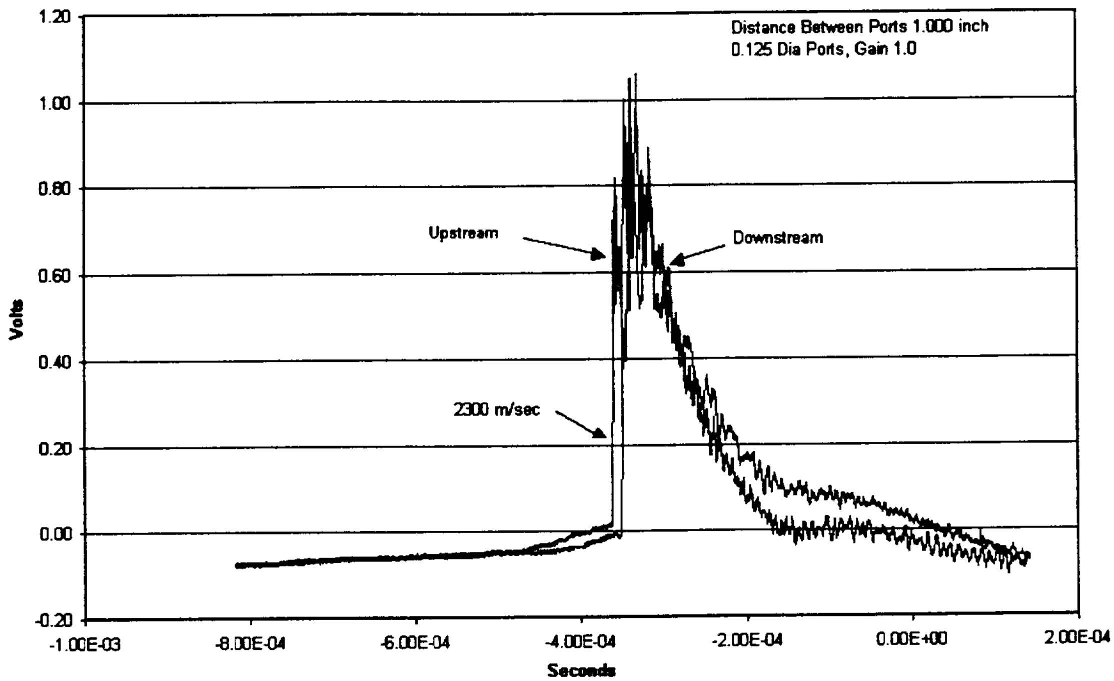


Figure 2. Detonation Velocity

A second initiator tube of the same design was built with the same initiator gas path as the verification tube but with the addition of a bolt pattern to attach to the primary tube and of ports for the primary gas flows. This tube was constructed out of stainless steel for durability. This tube has been used for all primary tube testing.

Task 2.0 Primary Pulse Detonation Tube

The second major task of this purchase order was the design, fabrication, and testing of the primary pulse detonation engine components.

The design was based on a 0.05 meter diameter by 1 meter length primary tube, basically a bench scale sized test unit. The head for the tube into which the initiator tube and primary valving are attached was designed around two inch flanges. One flange is screwed onto the tube while a blind flange was machined to hold the initiator tube and primary valving. The initiator is attached in the center of the tube while the primary fuel and oxidizer flows into the back of the primary tube thru annular injectors similar to the one in the initiator. The solenoid valves chosen for the primary tube are larger than those on the initiator tube. Also due to the larger volume of the tube there are four fuel and four oxidizer valves on the primary tube. These valves are rated for 1100 psig pressure and are operated on 60 volts DC, once again controlled thru solid-state relays with diodes to short circuit feedback from the solenoid collapsing. Figure 3 shows the blind flange with the four injector ports, eight valves radially located, and centered initiator tube.

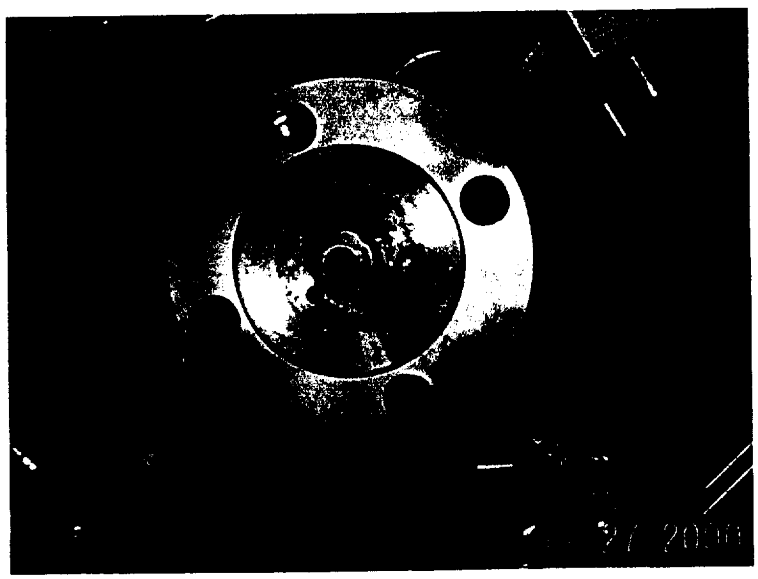


Figure 3. Primary Tube Head

The control program and isolation box were modified to control the extra channels required by the additional valving. Pressure taps where also placed on the primary tube at several positions along the length of the tube to measure detonation pressure and velocity. The stand for the primary tube incorporated rollers so that the tube was free to translate in horizontal direction. A plate with a force sensor was added to the back of the primary tube to facilitate thrust measurements.

At first it was thought based on the lack of necessity for water cooling in the initiator tube that water cooling would not be necessary in the primary tube as well, however this was not shown to be so during testing. Water cooled tubing was added to the outside of the primary tube, however this was only effective in removing heat in a limited area. A wick with a water spray was added to the tube and has been shown to be effective in keeping the tube cool.

Figure 4 shows the present configuration of the engine with the water-cooling wick removed. The initiator tube, primary valving, and the fuel and oxidizer headers are seen at the left of the figure. Helium bleed pressure transducers have been placed in two of the seven pressure taps located at the top of the main tube for measuring detonation pressure and speed. Sparkplug coils can also be seen behind the engine. The coils are controlled by three ignition modules located in a box mounted on the stand with the engine. The ignition modules are controlled by TTL signals through the use of cascaded transistors.

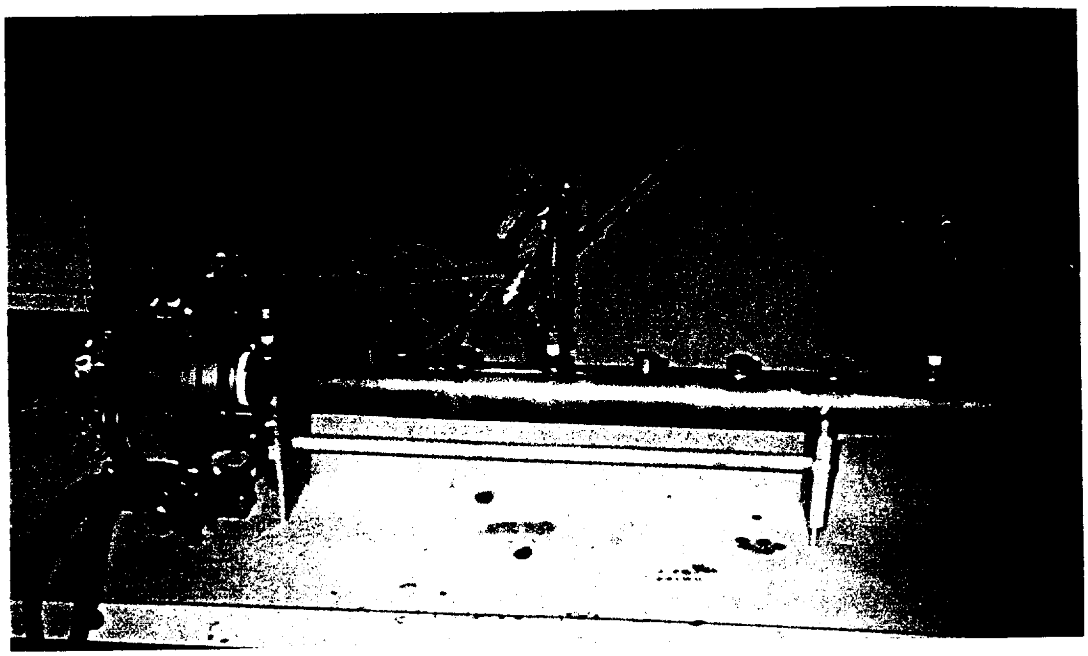


Figure 4. Engine

Testing

The engine has been tested on a number of occasions. It is a very impressive device when detonating due to the extremely high sound pressure generated and shock waves that can be felt by operators. It is readily apparent when the device does detonate due to the sound. During the first attempt at running the primary tube the oxygen pressure was set to high and a stainless steel mesh that had been added to the tube to increase turbulence caught on fire and burned. The mesh was removed from the tube and abandoned. More testing has shown that the device is sensitive to thermal and mixing events. If the tube is not properly cooled the tube will self ignite resulting in a deflagration instead of a detonation wave. Also the tube is sensitive to mixture and if the gases do not mix well a detonation will not occur and the tube may not even fire. Several things have been done to combat these problems. First as stated before a cooling wick has been added to the tube to keep the temperature down. Second a stainless steel plate has been designed, built, and added to the tube in front of the primary annular injectors to increase turbulence and therefore mixing. Finally two more spark plugs have been added to the back of the engine to insure ignition and detonation in the engine.

Presently the engine and stand are being moved to the test area where more operation of the engine is planned in 2001 with further diagnostic equipment to study the dynamics of engine operation for future scale up.

Task 3.0 Thrust Stands

Under this task equipment was designed, built, tested, and delivered to NASA Marshall personnel. The purpose of this equipment was to aid in the measurement of the thrust developed on a model designed to focus the light from a laser down such that it creates a local detonation in air. The measurements taken with the trust stands where to be used in validating code written to simulate the process. Also built was a calibration device to simulate single or multiple pulses from the high power laser being used in the actual experiments. TMET personnel aided NASA personnel in calibrating the thrust stands at NASA Marshall and traveled to White Sands New Mexico to setup and take data with the equipment at the high power laser facility there.

Thrust Simulation Device

The device built for this task was basically an helium gas powered gun that was capable of firing steel projectiles at 1 to 28 Hz at speeds in the range of 300 to 500 feet per second. Provisions where made on the barrel for optical sensors to measure the projectile velocity and timing to correlate to the impact on the thrust stands built in later tasks. The speed, mass, and firing rate of the projectiles where chosen to simulate the strength and frequency of the laser shots on the model. This calibration device was setup and fired at plates on the two thrust stands. From the mass, velocity, and number of projectiles fired at the stand a response to a given thrust input could be found. With known responses to a given input the actual thrust developed on the light craft could be found.

Horizontal and Vertical Thrust Stand

This stand was built with the intent of using it with the laser firing at the model repeatedly so the effects of multiple shots on thrust could be investigated. The stand was designed with a set of rollers that ran on hardened rails such that the model attached to them was allowed free translation in one direction only. The stand was also designed such that it could be rotated to hold the light craft model in the horizontal or vertical direction. It was also made to hold the LVDT, springs, and an air damper such that a damped response could be obtained from the laser induced detonation on the light craft model. Below in Figure 5 is a picture of the stand with the light craft mounted during testing at White Sands.

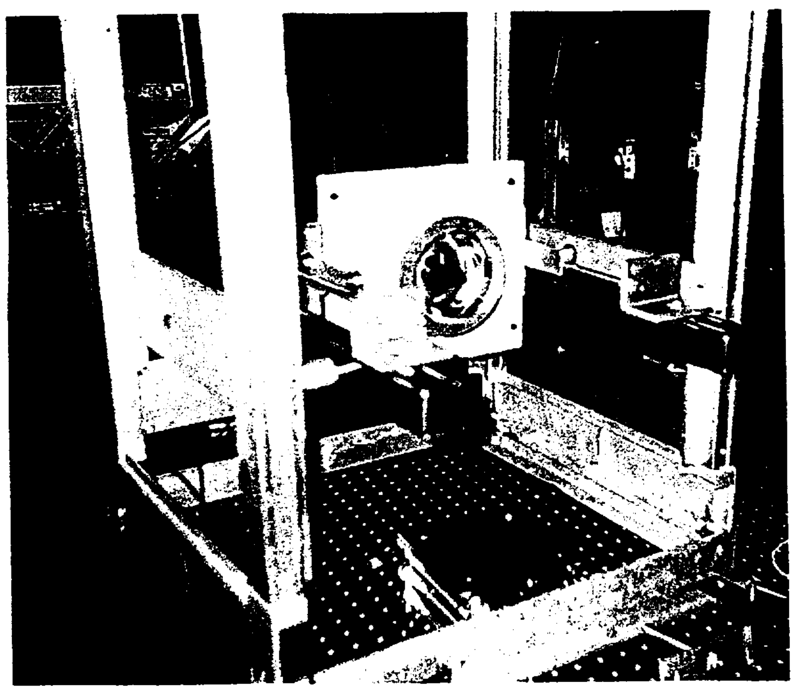


Figure 5. Horizontal/Vertical Thrust Stand

Pendulum Thrust Stand

A pendulum stand was designed and built out of light weight high strength materials including honeycomb board and outfitted with a linear variable displacement transducer (LVDT) to measure the pendulum displacement. The same frame was used to mount the pendulum stand and horizontal/vertical stand in to reduce the amount of equipment that had to be shipped to

White Sands. The pendulum stand was designed to be used with the laser operating in single shot mode and to compare data from another stand built by another contractor.

The stands and laser detonation simulation device that where built by TMET where tested and calibrated at NASA Marshall. TMET then assisted NASA PRC personnel in the transportation to and setup of the equipment at the White Sands Test Range where a high power laser used in the light craft research is located. TMET also assisted in the modification of the stands including the addition of a high bandwidth force sensor to the horizontal/vertical stand in preparation for a second trip to the White Sands Test Range.

Future Plans

The plans for year 2001 research include making the pulse detonation rocket engine more reliable and amiable for use with instrumentation. It is desired to add instrumentation for flow and pressure visualization to determine how the gas flows mix as they leave the injectors, what occurs in the tube, and what occurs at the exit of the tube for possible scale up in the future.

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